Documenting, Understanding, and Predicting the Aggregate Surface Radiation Fluxes for SHEBA

NASA Grant NAG5-4903

Final Report
Boston University

Project Period at Boston University:
June 15, 1997 - August 31, 1999

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February 10, 2000

PURPOSE

This document serves as a final report for NASA grant NAG5-4903 at Boston University. The report covers the first two years of the three-year project. The third year's funding and tasks have been transferred to the University of Wisconsin-Madison (UW) where the Principal Investigator (J. Key) is now stationed. The new UW grant number is NAG5-8625. Plans for the final project year at UW were detailed in the *Request to Transfer* document, submitted to NASA in July 1999.

This is a group project with the University of Colorado (CU) as the lead institution, where Judith Curry is the Principal Investigator. The overall project is jointly funded by NASA and NSF. The progress reported herein is that specific to Boston University, but no attempt has been made to separate NASA and NSF activities.

OBJECTIVES

The overall project addresses issues related to the cloud-radiation feedback and the ice-albedo feedback through a coordinated effort that utilizes aircraft and satellite observations in conjunction with surface-based observations from SHEBA. The field measurements will be used to developing an empirical and theoretical understanding of radiative transfer in the Arctic, which can be used to develop improved models for surface radiation properties and surface radiation fluxes.

Our specific objectives are to:

1. document the variations of surface characteristics, surface radiation fluxes and cloud characteristics on a horizontal scale of approximately $(60\ \mathrm{km})^2$ using research aircraft
2. use aircraft observations in concert with surface observations and models to develop an understanding of how the surface radiation flux components vary with surface and cloud characteristics
3. develop an empirical and theoretical understanding of 3-D radiative transfer in the Arctic and use this understanding to develop an improved parameterization of surface radiative characteristics and a 1-D radiative transfer model for the Arctic that can be used to determine surface radiative fluxes and the radiation feedbacks in climate models.
4. devise and test strategies to determine the aggregate-scale surface radiative flux components for each surface type during periods when aircraft is unavailable, using only surface and satellite observations in conjunction with models
5. create an integrated dataset of the aggregate-scale surface characteristics, surface flux components, and cloud characteristics for use by the SHEBA community in Phase III investigations

At Boston University, J. Key and two graduate students (one funded by NASA and one by NSF) addressed all of these to some degree, but are focussed on #2 and #3. Results to date are described in the next section.

SUMMARY OF PROGRESS AND ACCOMPLISHMENTS

Progress has been made in three areas: (1) modeling and empirical studies of the effects of clouds on the surface temperature, (2) modeling the effects of cloud horizontal and vertical inhomogeneity on surface fluxes, and (3) satellite-retrievals of cloud and surface properties for the SHEBA period.

The Influence of Clouds on Surface Temperature

In the Arctic cloud cover is extensive at all times of the year, with monthly means ranging from 50-80%. Retrievals of the clear sky surface temperature are therefore of limited utility for climate studies. Is it possible to estimate the surface temperature under cloud cover from thermal satellite data? Previous studies have used nighttime data to examine the relationship between clouds and surface temperature. Here a thermodynamic model is used to extend the analyses to daytime conditions. The thermodynamic model includes radiative transfer, sea ice/snow energy balance, and atmospheric turbulence components.

Figure 1 illustrates the effect of clouds on the surface temperature of sea ice. The results shown were determined with SCCM, a single column version of NCAR's CCM3 climate model. All other surface and atmospheric properties were held constant while cloud optical depth was varied.

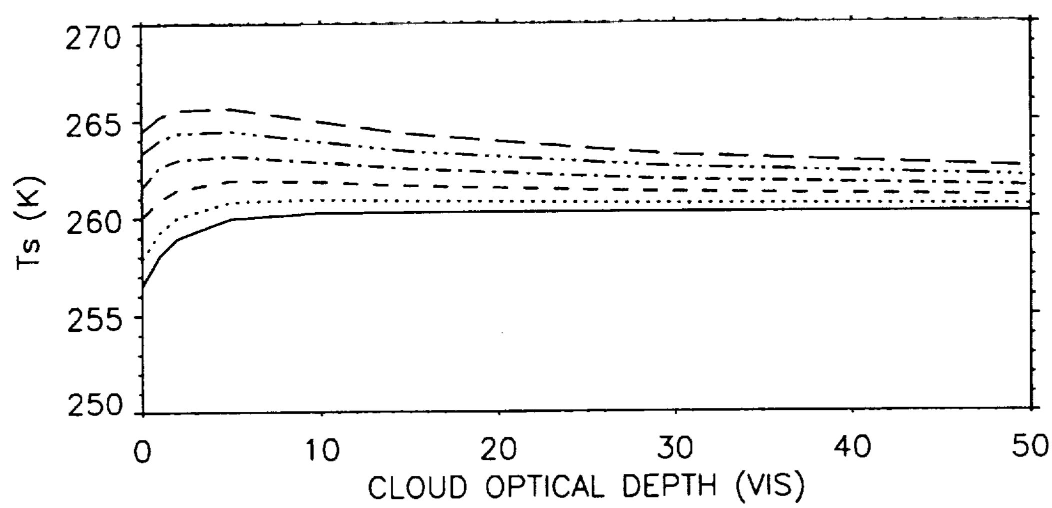


Fig. 1. Modeled (SCCM) change in the surface temperature of sea ice with a change in visible cloud optical depth. Lines correspond to different solar zenith angles from 90 degrees (bottom, solid line) to 40 degrees (top) in increments of 10 degrees. For this simulation the ice thickness is 2 m, snow depth is 20 cm, and the wind speed is 3 m/s.

Figure 2 shows the modeled surface temperature of sea ice over time, for transitions from cloudy to clear and back to cloudy with a fixed cloud optical depth. Results are given for a variety of wind speeds and for fixed cloud and surface properties. The figure illustrates the effect of clouds on the surface temperature during a transition from cloudy to clear conditions during the day and at night (no solar radiation). The warming effect of clouds at night is readily apparent, as is the cooling effect during the day. The rate of cooling or warming depends on the near-surface winds, ice and snow thickness, and cloud properties. An equilibrium surface temperature model with atmospheric turbulence was used to generate the data in Figure 2. Unlike SCCM, the surface temperature adjusts to changes in cloud cover almost immediately.

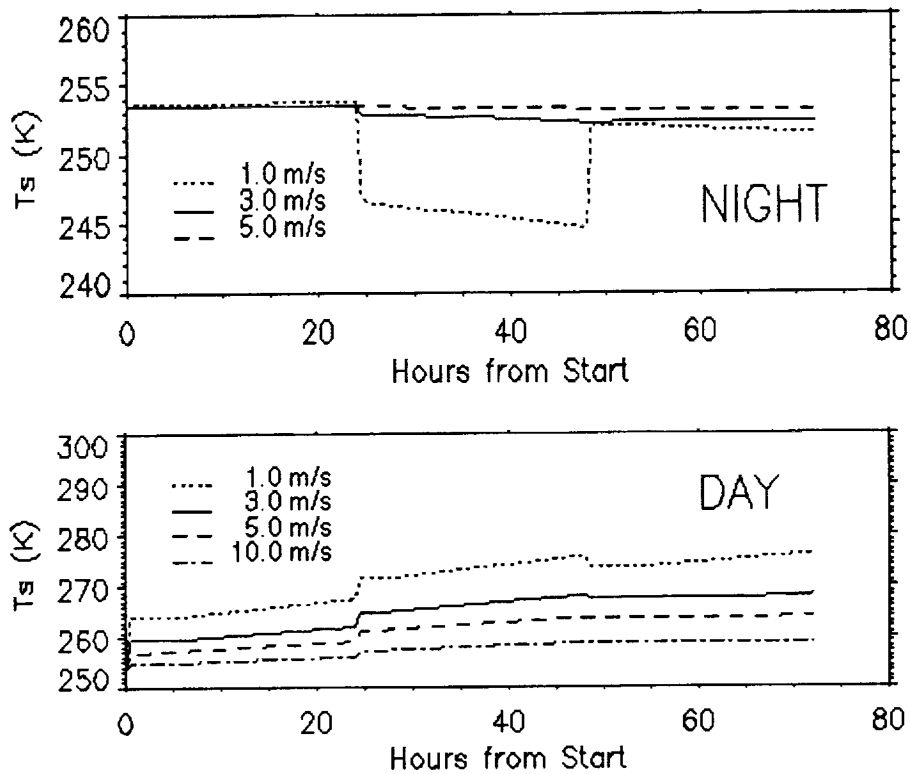


Fig. 2. Modeled (not SCCM) surface temperature over time for nighttime (top) and daytime (bottom) cases, and for various wind speeds. The time series incorporates transitions from cloudy to clear after 24 hours, then to cloudy again at hour 48.

If we could accurately simulate changes in surface temperature with a model, we could conceivably develop a parameterization of the cloudy sky temperature as a function of the previous (or nearby) clear sky temperature, cloud optical depth, and near-surface wind speed. Such a parameterization could be used to provide a spatially complete satellite-derived surface temperature product. However, SCCM does not appear to be adjusting the surface temperature under clear-cloudy transitions quickly enough. SHEBA surface observations show wintertime changes of 5-15 degrees within 6-12 hours, but SCCM takes more than 24 hours for a change of that magnitude. This problem is under investigation.

The Effects of Horizontal Variability of Cloud on the Surface Radiation Budget

One of the primary goals of our project is to assess the effect of 3-dimensional (3D) surface and cloud structure on large-area aggregate fluxes and satellite retrievals of cloud and surface properties. We have begun the investigation using the 3D radiative transfer model SHDOM, written by F. Evans (Univ. of Colorado), a Co-PI on the project. Figure 3 illustrates the effect of horizontal variability of cloud optical depth on downwelling visible fluxes as a function of solar zenith angle and surface albedo. The plot gives average optical depths over a hypothetical cell (e.g., a GCM grid cell), with varying optical depths but identical geometrical thickness at every point in the cell. Clearly, the assumption of a horizontal, uniform cloud layer, as often used in GCMs, can result in significant errors in fluxes. Errors in top-of-atmosphere radiances are expected to be much larger. Experiments such as this will be used to assess the uncertainty in aggregate fluxes due to 3D variability, and will (hopefully) lead to a method of parameterizing 3D effects in a 1D radiative transfer model. Additionally, we hope that this work can lead to a method of correcting what we believe are large errors in satellite retrievals of cloud optical depth at low sun angles.

Estimating Cloud and Surface Properties from AVHRR Data

Cloud and surface properties have been estimated from AVHRR data for the SHEBA year. The results presented here are preliminary (i.e., version 0) and may change in future retrievals. Five kilometer data from the AVHRR Polar Pathfinder project were used in in the analyses. The retrieval algorithms of the Cloud and Surface Parameter Retrieval system were applied (CASPR; http://stratus.ssec.wisc.edu/caspr/caspr.html).

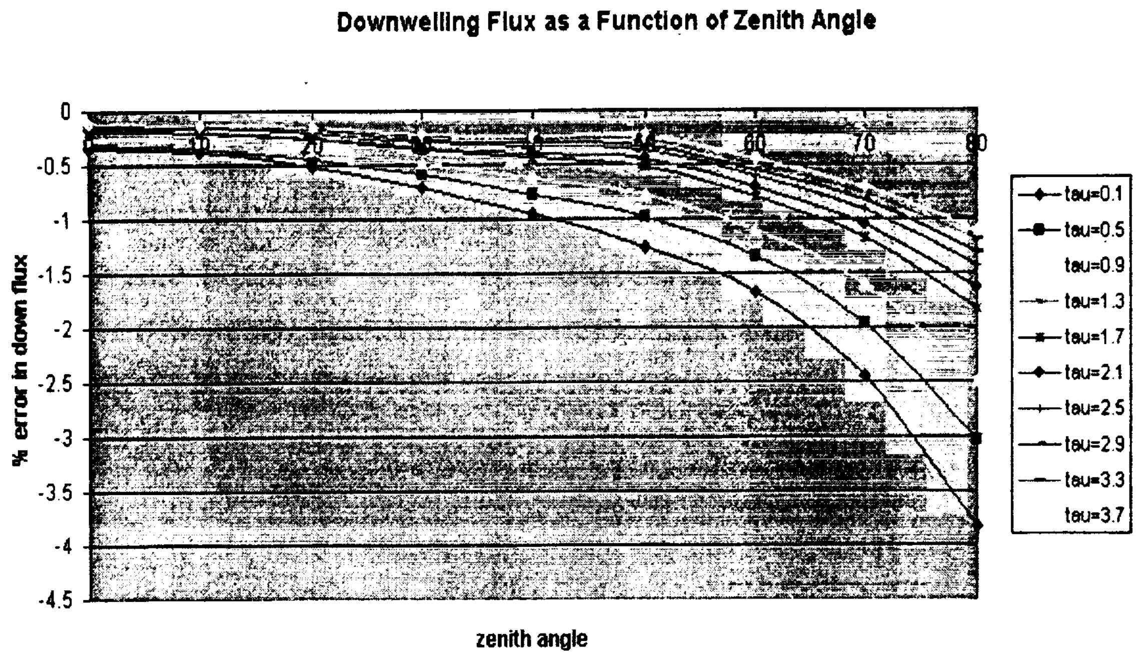
Time series of area averaged results are shown in Figure 4. The area covered by the AVHRR subsets extends from central Alaska to the North Pole, and from Banks Island to the Laptev Sea. The plots give the mean values over the entire image area. Time is shown as decimal year, where 98.0 is January 1, 1998. Results for cloud pressure and surface radiative fluxes are not given for periods with no radiosonde data. Additional results are provided on the SHEBA remote sensing group web site here at BU (http://stratus.ssec.wisc.edu/sheba).

While there are some obvious outliers in the results, of greater concern are the large cloud optical depths during the spring. These may be the result of unmodeled three-dimensional radiative transfer effects at low sun angles. However, the fact that such large optical depths are not observed during the fall implies that either the vertical and horizontal cloud structure is not important or that springtime clouds have a different morphology than clouds in the fall.

Comparisons of these satellite-derived cloud and surface properties with surface observations are in progress, using dates identified by the remote sensing group at the last SHEBA investigators meeting (Tucson, January 1999).

Plans for the Final Project Year

During the final project year we will will continue work on the surface temperature under cloud cover and on the effect of horizontal variability on aggregate area surface fluxes, including three-dimensional effect. Satellite retrievals will be refined and results will be made available to other SHEBA investigators. Validation studies will be done using surface and aircraft observations collected during the experiment. Much of this work is already underway.



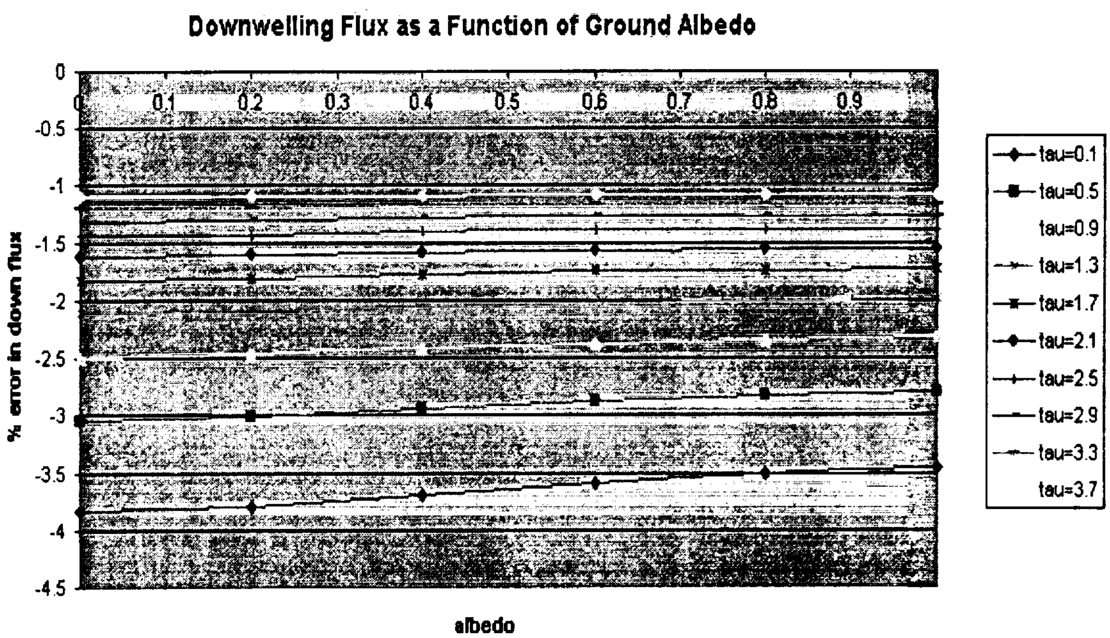
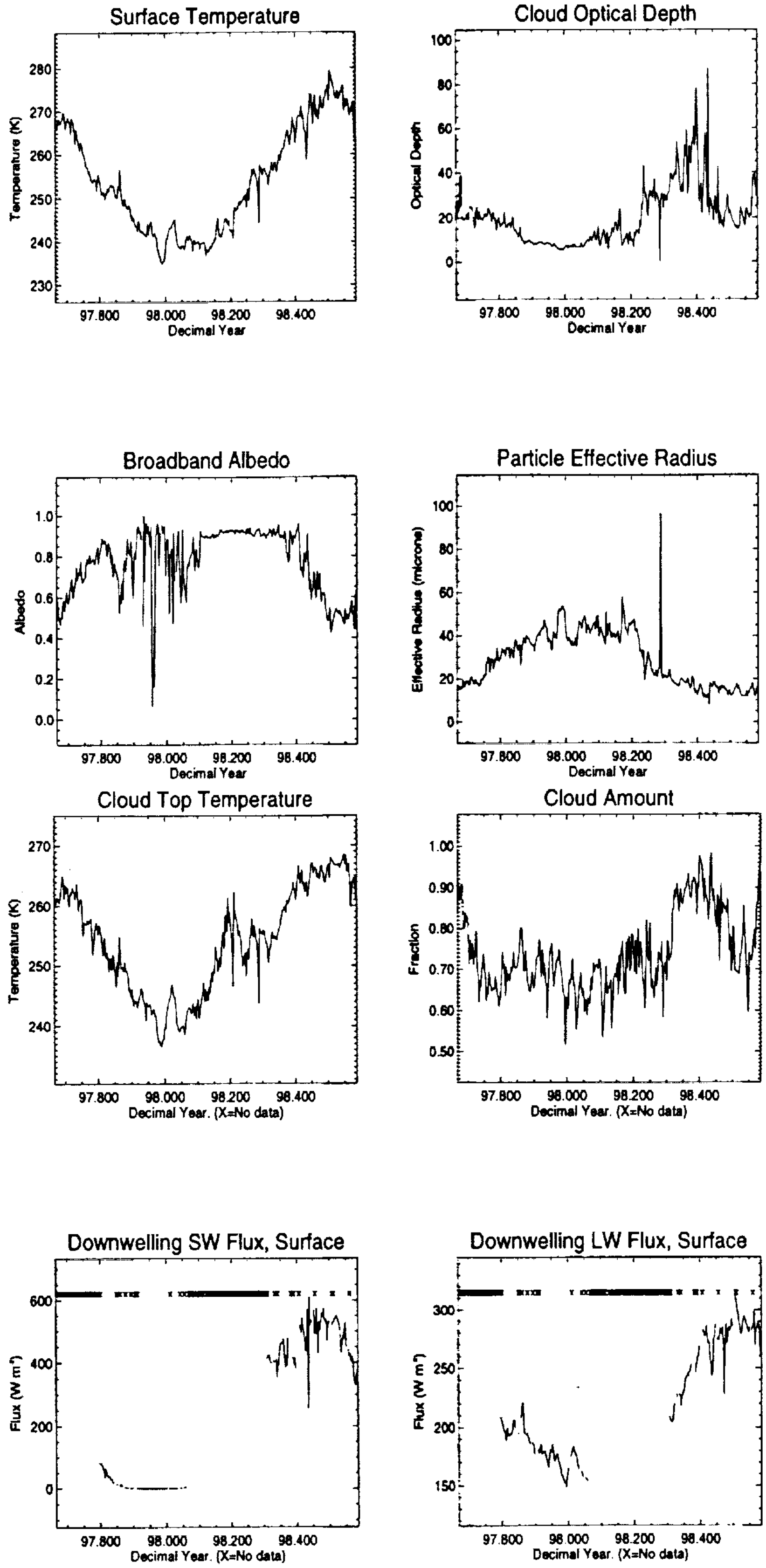


Fig. 3. Differences ("error") in downwelling visible (narrow band) flux at the surface computed using one-dimensional and three-dimensional radiative transfer models over a range of cloud optical depths. The top plot shows the error as a function of solar zenith angle; the bottom plot gives the error as a function of surface albedo.

Fig. 4. Satellite retrievals of cloud and surface properties for the SHEBA region using AVHRR data. The area covered is from central Alaska to the North Pole, and from Banks Island to the Laptev Sea. Shown are area averages for the SHEBA year, where decimal year 98.0 is January 1, 1998.



PUBLICATIONS SUPPORTED BY NAG5-4903 AND OPP-9701757

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In preparation:

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Additionally, A.M. Wong's Master's thesis is in preparation (expected completion in August 1999). It deals with the remote sensing of the cloudy-sky surface temperature.

INVENTIONS

There were no inventions.